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LARPD-584LF

DATED 12 Jan 1954

ENGINEERING REPORT

SECURITY INFORMATION

REPORT NO: RR-20 DATE: January 15, 1954

TITLE: PULSE-JET ANALOG

MODEL NO.

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or Changed to

Authority: *Comdr. WARE*

By: *777*

Date: *14 May 54*

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CONTRACT NO. AF 33(600) - 5860
E. O. NO. X506-230

REVISIONS:

PREPARED BY:

Paul S. Veneklasen
Paul S. Veneklasen
Consultant in Acoustics

APPROVED BY:

R. W. McJones
R. W. McJones
Chief Power Plant Engineer



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1.0 SUMMARY

During this report period another parameter has been included in the study of Pulse-Jet engines by means of the Pulse-Jet Analog.

Report No. RR-19 has described the circuits and techniques which are used in the tests. Fig. 3.2-1 of that report should be reviewed.

The present studies have included Frequency as a variable parameter. Pulse Length and Valve Forward Resistance are also shown as variable parameters. Techniques of operating the Analog have been improved as well as methods of presenting data. It is found that pulsing frequency is a very important factor in the system, and that the optimum frequency for an engine having low valve resistance is very different as compared with one having high valve resistance.

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2.0 INTRODUCTION

This report describes work accomplished on item 1.7 of Exhibit A, Supplementary Agreement No. 5 of Contract AF33(600)-5860 during the months of October and November, 1953.

This is the second report to be submitted describing the use of the Pulse-Jet Analog as a design tool for development purposes. The report is submitted by the American Helicopter Co., Inc., describing the study program being conducted by Paul S. Veneklasen, Consultant in Acoustics.

The work was carried out and is reported by Paul S. Veneklasen, and staff members W. B. Snow, G. F. Brockett, M. O. Herwick, and D. E. Talbert.

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3.0 DISCUSSION

The tests described in this report were designed to show the effect of pulse frequency, pulse length and valve resistance upon Thrust, and Specific Thrust. The same circuit configuration was employed as for the tests described in Report No. RR-19 for September, 1953. Fig. No. 3.1 illustrates the effects for a single pulse length and valve forward resistance for a range of pulse frequencies, from 150 cps to 1050 cps. At the lowest frequency the pulse energy is completely dissipated some time before the next pulse arrives; at the highest frequency the Line is driven at its fundamental quarter-wave resonant frequency. As in the previous report, each figure shows the Source Current, Line Input Voltage, Valve Input Current and Line Output Current for a particular pulse frequency, arranged in a vertical pattern which shows the time relationships accurately.

For example, consider Fig. 3.1-B, for a pulse frequency of 250 cps. Pulse length was generated by a 1.0 henry inductance and a .022 mf condenser and Valve Forward Resistance was 650 ohms. The top wave form shows the imposed input pulse of Source Current, always adjusted to a peak amplitude of 7 milliamperes. Note that the 'rest' portion of the curve is .8 division below the reference axis, an adjustment made, as described in RR-19, to achieve zero average dc current into the Line. This means that the area under the positive spike above the reference line is equal to the area between the wave-form and reference line during the rest portion.

The Thrust, given by the second wave-form, is the voltage generated across the Line input by the Source Current pulse shown by the large positive spike, and by reflected current due to wave action, shown by the oscillating damped wave train below the reference axis. In this example the wave is almost completely damped at the time of the next pulse. Average thrust is the average of the positive and negative portions of this curve; although the negative phase lasts longer than the positive pulse, the positive area is greater and positive net thrust is obtained.

It should be observed that the positive spike of Line Input Voltage is essentially in phase with the Source Current pulse. This is because the Line presents Characteristic Resistance to a short pulse when it is at rest, even though its impedance elements are essentially reactive, and accepts energy from the Source for transmission down the Line. In this case the ratio of peak voltage to peak current is 4300 ohms - essentially theoretical Characteristic Resistance.

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The third wave-form shows Valve Input Current. The short flat portion just preceding the first negative spike represents the time during the input pulse when the diode valve is closed. When the input pulse is over, reflected negative voltage arrives after a round trip down the Line and back, as shown by the Line Input Voltage. This causes the valve to open and current flows into the Line, which is proportional to the negative position of the Line Input Voltage. This current is in phase with the voltage, and represents loss of energy in the 650 ohm valve resistance.

At the bottom appears the wave-form of the Line Output Current. The first positive spike is the current resulting from the arrival, at the output end of the Line, of the original Source Current pulse, one-quarter of a fundamental period later. This spike is reflected as a negative pulse which is the first negative spike of Line Input Voltage, and since the valve impedance is below Characteristic, this is in turn inverted upon reflection. Consequently, the second spike of Line Output Current is in the same direction as the first one and represents the arrival of the first reflection from the valve end, three-quarters of a fundamental period after the Source Current Pulse. The reflections succeed each other until the pulse energy has been dissipated.

Other pictures in this series illustrate conditions when higher pulse frequencies are employed. Interactions occur between original and reflected pulses. They will be discussed after presentation of some intermediate data, but two pictures should be inspected in preparation. In Fig. 3.2A the Line Input Voltage is shown for the same conditions except that valve resistance is 2000 ohms. It will be seen that the oscillations are reduced essentially to zero in a shorter time than for 650 ohms, since this picture was taken at a pulsing frequency of 400 cps. Fig. 3.3A is again for the 650 valve resistance except a very short pulse is used; the action is essentially the same as before, although there are evidently small secondary oscillations caused by high frequencies characteristic of this limiting pulse length.

Using conditions exemplified by the photographs, two sets of data were taken, varying different parameters, and shown in Figs. 3.4, 3.5, 3.6 and recorded in Table 3.7. These are plots of Thrust and Specific Thrust as functions of pulse frequency, where Specific Thrust is the average Line Input Voltage divided by Total Source Current.

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Figure 3.4 illustrates the effect of pulse frequency on Thrust for the constant "medium" pulse width ($L=1.0$ hy, $C=0.022$ uf) as used in the previous extended series of photographs, where Valve Forward Resistance is the parameter on the curves.

At very low pulse frequencies the Thrust rises in a smooth curve. In this region the oscillation decays completely between pulses, so that average Thrust depends only on how often a pulse occurs. It is apparent that Thrust increases for lower values of valve resistance, as pointed out in Report RR-19. Primarily, this is because of the reduction in the negative pressure across the valves, which produces a negative Thrust.

At the bottom the curve for 4000 ohms, essentially characteristic impedance, is smooth and reaches a broad maximum near the fundamental resonance of the quarter-wave Line. In this case most of the reflected energy is absorbed in valve resistance on the first reflection, so that the wave action is small. The high valve resistance causes a large negative voltage loop, which subtracts from the positive spike and causes the low value of Thrust. As the valve resistance is lowered, less energy is dissipated in it and Thrust increases as the other curves demonstrate. The wave motion is greater since the reflections are less damped.

As the pulse frequency increases, the curves begin to show maxima and minima, which increase in amplitude. They also level off. These effects are caused by the particular phase relation between the pulse and the reflected wave motion in the Line at the time of pulsing. When the Line voltage is highly negative at the instant the pulse tries to drive it positive, a smaller peak Thrust results and consequently smaller average Thrust.

In Fig. 3.4 the oscilloscope traces in Fig. 3.1 are associated with points along the curve of 650 ohms valve resistance, and those of Fig. 3.2 are associated with the curve for 2000 ohm valve resistance.

Although we propose to limit ourselves in this report to presentation of data, it is interesting to note that the frequency of greatest Thrust for a high valve impedance (this is the frequency of quarter-wave resonance of the Line, and the frequency at which present engines appear to operate) is the frequency of minimum Thrust when a lower value of Valve Forward Resistance is used. Note especially



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that the curves for Fig. 3.2-2 in Report RR-19 were all for this frequency. It is now clear that the improvements in performance which were predicted there were based upon the least favorable operating condition for the engine with low impedance valves.

In Fig. 3.5 the curves of Fig. 3.4 are replotted in terms of Specific Thrust. This is done for the following reason: The Analog is, in each case, adjusted for a constant value of peak source current. This means that the Total Source Current will depend upon the pulse length. Also, for a given pulse length and peak current, all pulses are identical. Therefore, the Total Source Current will be proportional to frequency - i.e. the number of pulses per second. Hence the curves of Fig. 3.4 have inherently a variable Total Source Current, i.e. equivalent of a variable fuel flow. This variable must be taken out in order to present performance in a significant light. The graph of Fig. 3.5 shows the variation in performance to be expected with a constant rate of fuel flow. As compared with the performance at 1000 cps and a high valve resistance, the potential improvement would seem to be startling with the use of low Valve Forward Resistance and low operating frequency. This implies the use of controlled fuel injection.

The curves of Figs. 3.4 and 3.5 have been for a constant, medium value of pulse length. Since pulse length is also considered to be a factor of considerable importance, the study of this parameter of the system was also undertaken as a function of frequency. As noted in the previous paragraph, when the pulse length is varied, keeping a constant peak current, the results are not readily interpreted as Specific Thrust. Accordingly, the conversion of the data to Specific Thrust was accomplished in the presentation of the results in Fig. 3.6. Furthermore, although data for short pulses at low frequency was taken, the meter readings became too small for good accuracy. Although they are shown in Table 3.7, such results are not included in the graph and will require further study with more sensitive meters.

It is readily apparent that the shorter pulse lengths do provide improved performance of the Analog for the low value of Valve Forward Resistance of 650 ohms. It is also clear that the frequency of 1000 cps used for the study in RR-19 was not favorable for this operating condition, because very much larger values of Specific Thrust are achieved at neighboring frequencies.

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We limit ourselves here to presentation of the data. Next month's report will present further information which may be derived from the present data by way of explanation and correlation.

We wish to indicate, however, that in evaluating the effectiveness of a given engine configuration, as predicted by the Analog, several factors must be considered which are not necessarily cooperative, but must be compromised.

1. Specific Thrust is the best indicator of overall economy of performance.
2. Maximum Thrust per unit weight is important for an aircraft power plant.
3. Maximum Thrust per unit volume is important for drag considerations.

A given configuration may not be optimum for all these factors at the same time so that in judging the prospects of a given engine configuration a proper compromise must be evaluated.

We wish to point out that the data which is derived from the Analog has implications and may be judged in relation to these three factors at least. For example: Compare Fig. 3.4 and Fig. 3.5. From the point of view of economy, it would appear desirable to operate at a very low pulse frequency, gaining the full benefit of the sustaining resonance of the tube. But, since Thrust decreases at low frequencies, the size and weight of the package would have to increase to achieve the necessary Thrust at a low operating frequency. A compromise is obviously required. However, with low valve impedance, the frequency of maximum Thrust is very much lower than present operating frequencies, giving probable additional advantage of lower operating temperature. Such factors and the reasons for them become still more apparent in the correlation work which is now in progress.



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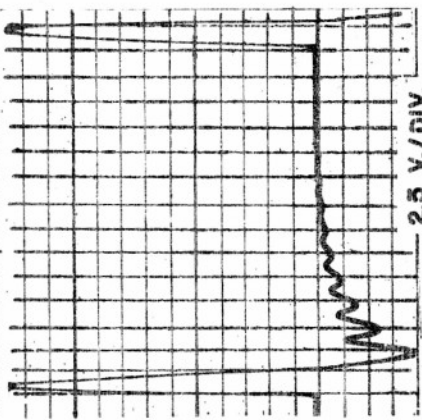
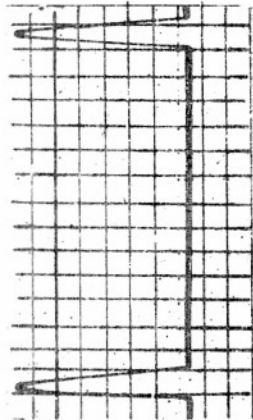
DATE 13 Jan 1954

4.0 CONCLUSIONS

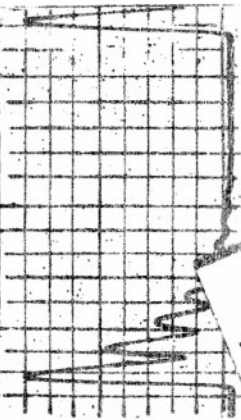
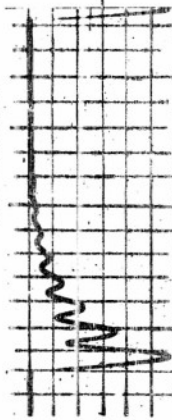
- A. It has been shown that the driving pulse frequency is a very important parameter in Pulse-Jet performance.
- B. For an engine having high Valve Forward Resistance, as we judge the present engines to have, the frequency for maximum Specific Thrust is equal to the quarter-wave resonant frequency for the tube, or electrical line in the case of the Analog. For such an engine the performance peak is very broad.
- C. For an engine having a low value of Valve Forward Resistance the performance is minimum at the quarter-wave frequency. There are many frequencies of high performance indicating that there are several strong resonant modes to which the system will respond. The performance in all these modes far exceeds that of the high resistance engine. A frequency of operation can be chosen which gives the desired compromise between maximum Thrust and maximum Specific Thrust, depending upon whether economy or or thrust to weight ratio is of greater importance. In fact, with an engine operating on an imposed frequency cycle, as with fuel injection, a high pulse frequency could be used for periods requiring highest performance, and a lower frequency could be used for periods of cruising where greatest economy is desired.
- D. The strength of the resonant modes depends upon the valve resistance and the pulse length. It is shown that the resonance is improved and the performance is maximized by using the lowest possible valve resistance and the shortest pulse length.
- E. The present study has been limited to medium pulse length, but it seems clear that when technical development permits the use of shorter pulses, even higher values of Specific Thrust will be predicted.
- F. The present report is limited to presentation of data. Further data showing interpretation and correlation of results is in preparation.

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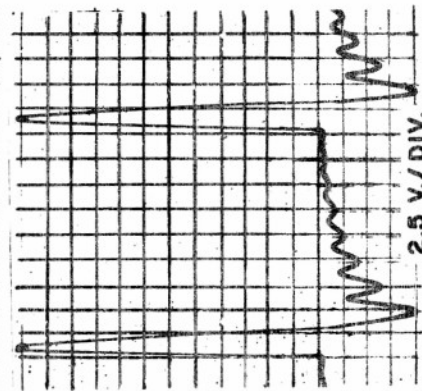
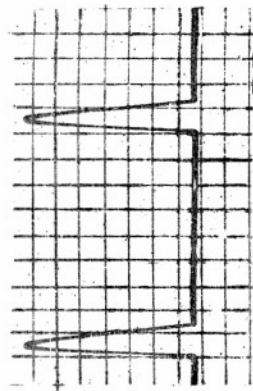
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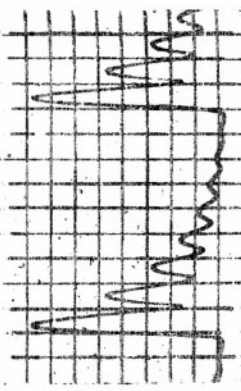
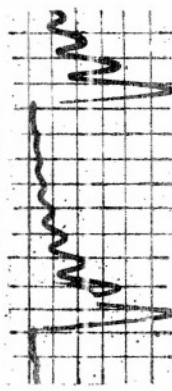
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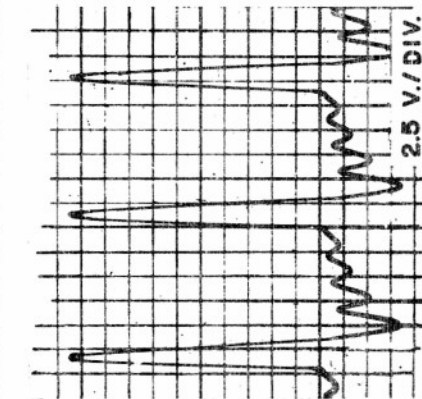
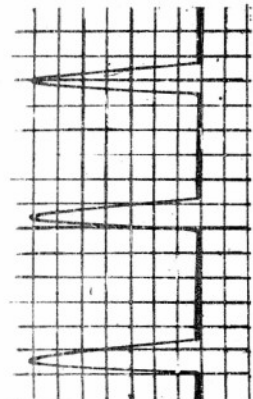
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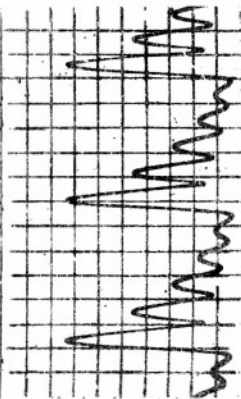
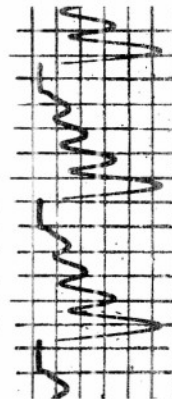
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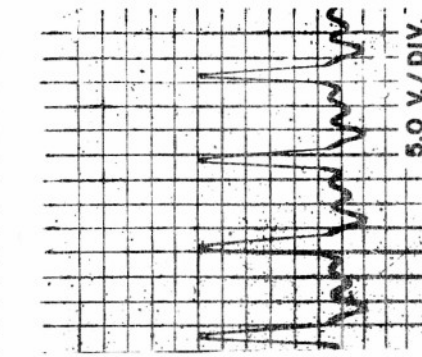
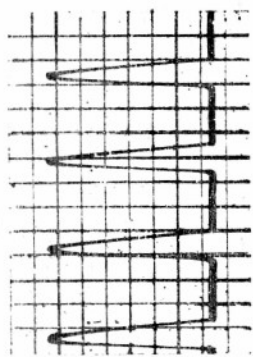
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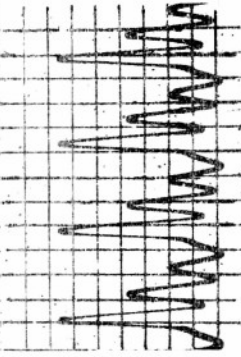
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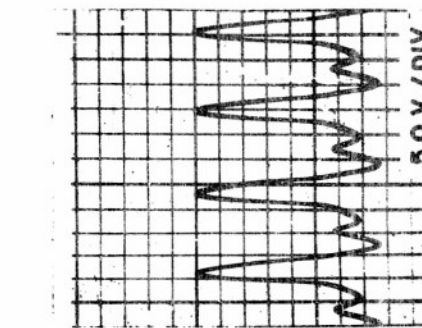
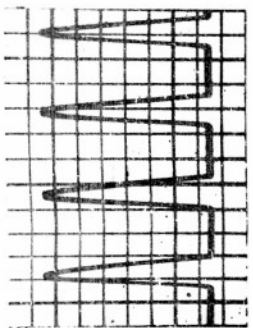
400 CPS.



5.0 V./DIV.



600 CPS.



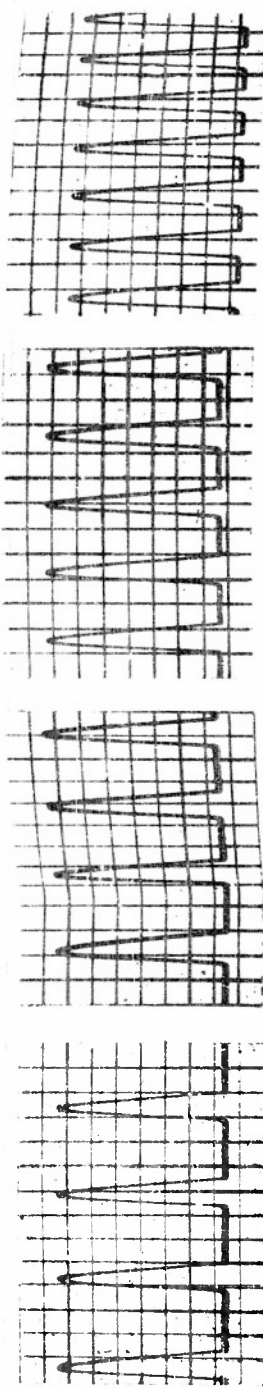
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720 CPS.

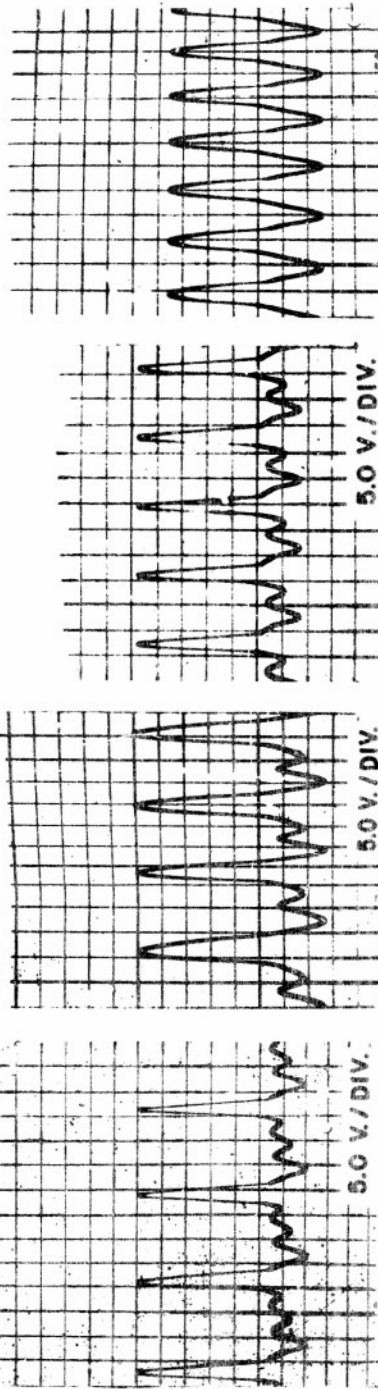
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SOURCE CURRENT
1 MA./DIV.

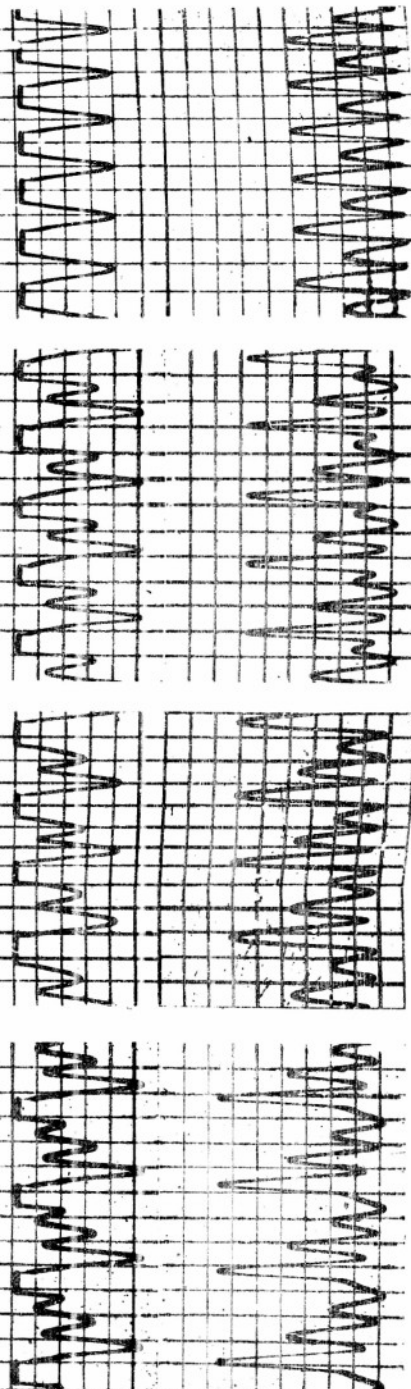


PULSE LENGTH = $.54 \times 10^{-3}$ SEC.
VALVE FORWARD RESISTANCE
= 650 OHMS

LINE INPUT VOLTAGE



VALVE INPUT CURRENT
2.0 MA./DIV.



LINE OUTPUT CURRENT
1.66 MA./DIV.

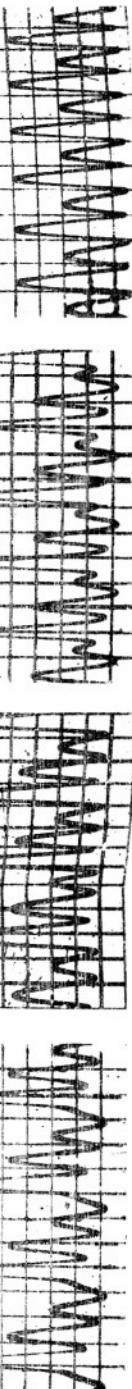


FIG. 3.1

F R E Q U E N C Y

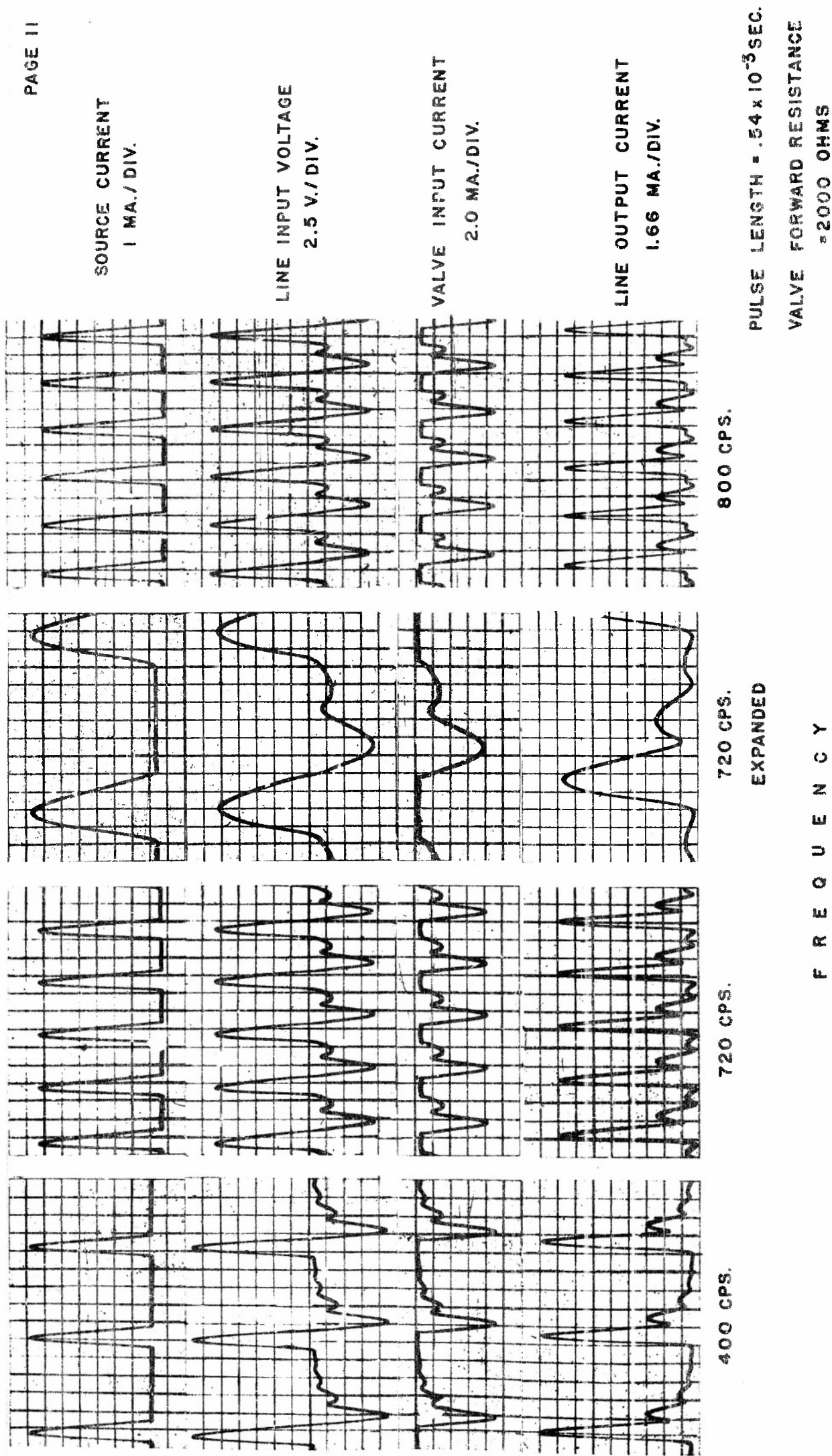
600 CPS.

720 CPS.

800 CPS.

1050 CPS.

2



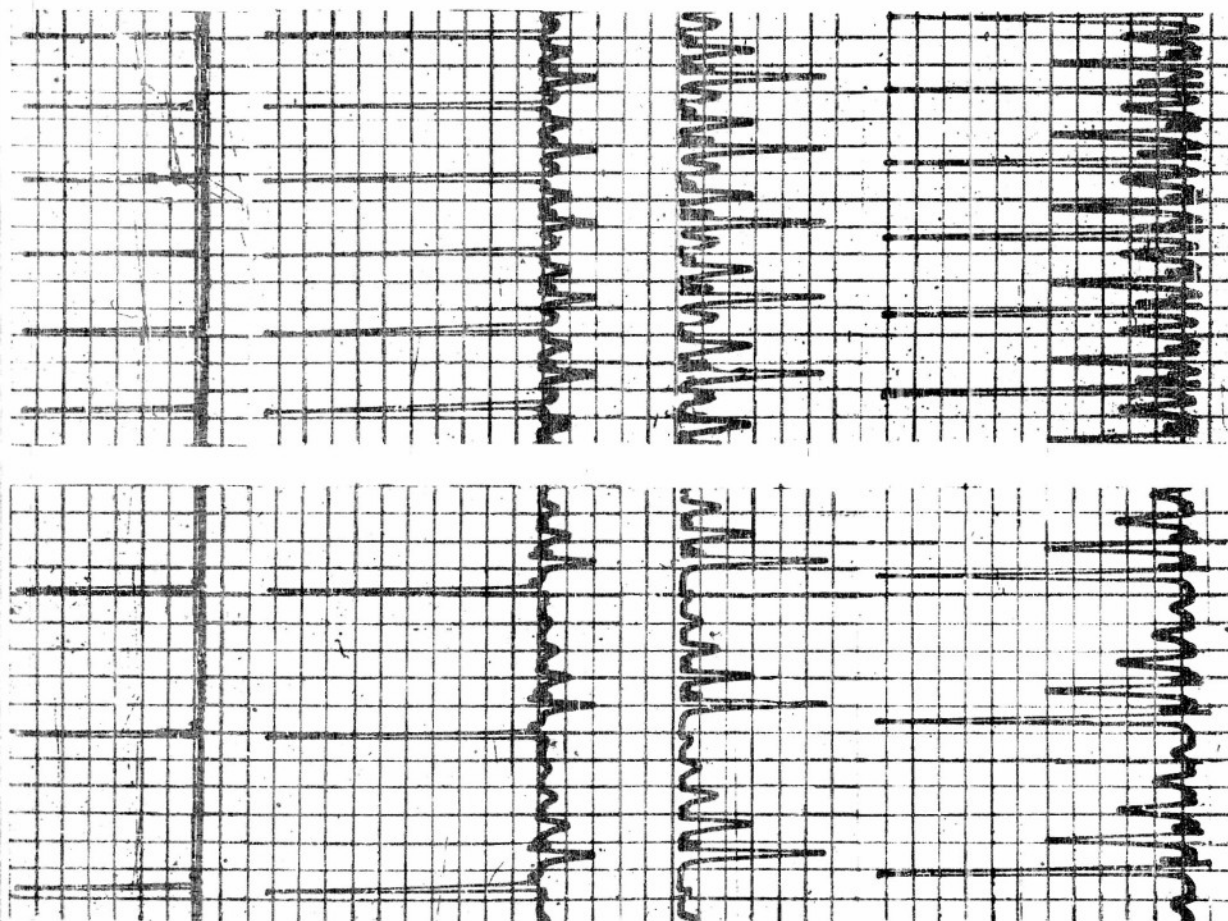
SOURCE CURRENT
1 MA./DIV.

LINE INPUT VOLTAGE
5.0 V./DIV.

VALVE INPUT CURRENT
1 MA./DIV.

LINE OUTPUT CURRENT
.66 MA./DIV.

PULSE LENGTH = $.13 \times 10^{-3}$ SEC.
VALVE FORWARD RESISTANCE
= 650 OHMS



400 CPS.

800 CPS.

F R E Q U E N C Y

THRUST AS A FUNCTION OF FREQUENCY
AND VALVE FORWARD RESISTANCE

FIG. 3.4

Pulse Length = 5.4×10^{-3} sec.

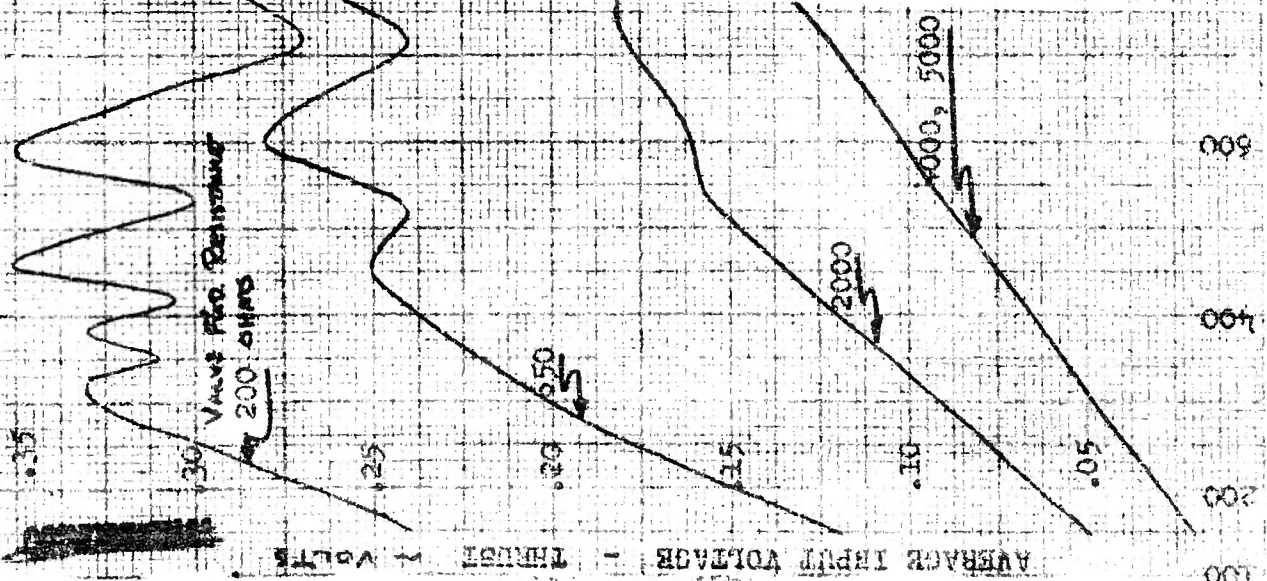
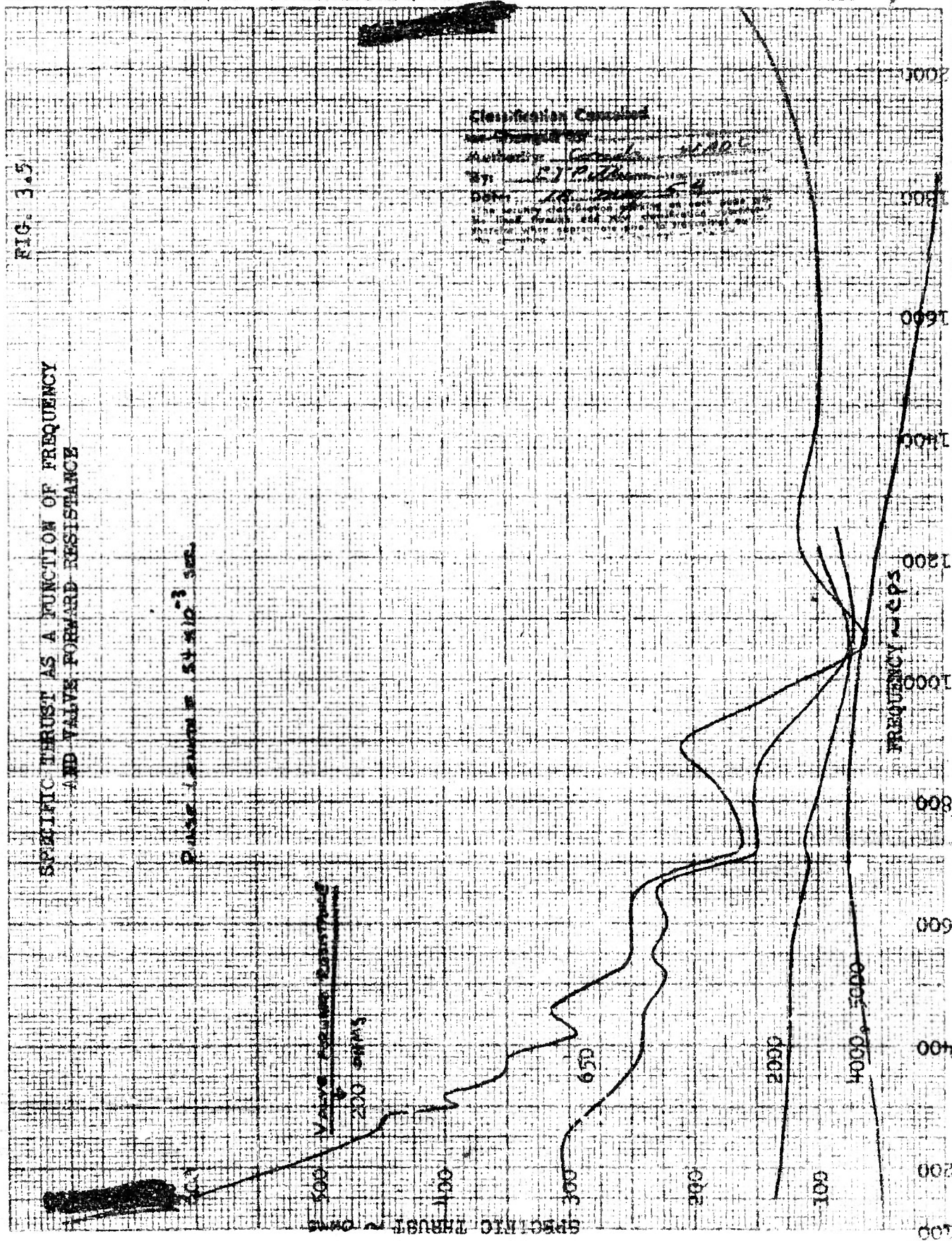
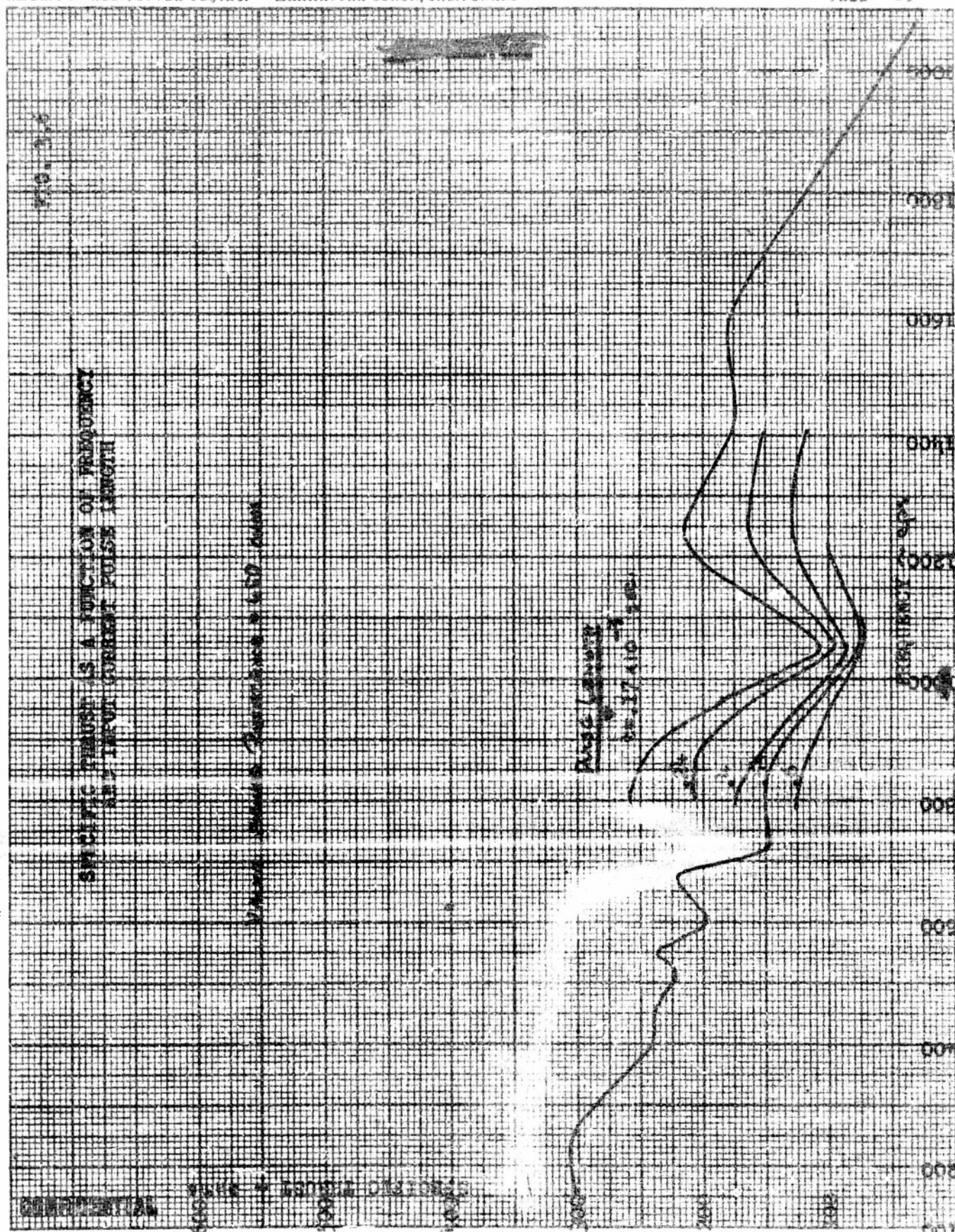


FIG. 3.5

SPECIFIC THRUST AS A FUNCTION OF FREQUENCY
AND VALVE FORWARD RESISTANCE





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TABLE 3.7

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1	54	150	.54	650	.40	.12	1.55	302
2	58	250			.59	.18	2.57	305
3	62	400			.97	.235	3.11	242
4		450			1.04	.25		240
5		520			1.09	.24		220
6	66	600			1.44	.28	3.65	195
7	125	720			1.63	.24	3.18	147
8	70	800			1.78	.27	3.51	152
9		880			1.85	.26		141
10	74	1050			2.28	.17	2.41	74
11		1220			2.52	.255		101
12		150	.54	2000	.37	.05	.665	135
13	78	400			.98	.12	1.65	122
14		520			1.27	.155		122
15		600			1.37	.16	2.22	117
16	149, 153	720			1.66	.18	2.23	108
17		730			1.66	.185		111
18	82	800			1.77	.18	2.51	102
19		1050			2.30	.165	2.20	72
20		1250			2.59	.18		69
21		150	.54	4000	.38	.02	.396	53
22		520			1.24	.09	1.19	72
23		720			1.51	.12	1.58	72
24		800			1.85	.145	1.87	78
25		1050			2.32	.155	1.98	67
26		2180			3.32	.00	.072	0
27		150	.54	5000	1.17	.075	1.04	64
28		480			1.21	.08	1.08	66
29		630			1.65	.10	1.30	61
30		850			2.22	.15		68
31		1050			2.66	.16	2.10	60
32		1400			3.14	.10	1.37	32

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DATE 13 June 1954

TABLE 3.7
(continued)

REC. PHOTO	PULSE FREQ. cps	PULSE LENGTH $\times 10^{-3}$	VALVE FORWARD RESIST- ANCE ohms	TOTAL SOURCE CURRENT ma	INPUT VOLT. volts	VALVE INPUT CURRENT and LINE OUTPUT CURRENT ma	SPEC. THRUST ohms
33	150	.54	200	.40	.24	3.00	602
34	268			.67	.30	3.92	450
35	280			.71	.32	4.78	450
36	300			.82	.32	4.07	389
37	320			.824	.33	4.29	400
38	350			.88	.31	4.13	352
39	380			.944	.33	4.36	350
40	420			1.05	.305	4.06	290
41	460			1.11	.35	4.57	315
42	535			1.20	.30	3.96	250
43	590			1.41	.35	4.64	248
44	720			1.65	.27	3.61	163
45	800			1.85	.32	4.42	173
46	890			2.07	.33	4.36	260
47	1060			2.37	.20	2.76	59
48	1220			2.62	.30	3.85	114
49	1400			2.74	.27	3.64	98
50	1500			3.03	.30	3.85	99
51	2180			3.44	.04		116
52	2500			3.55	.24		68
53	150	.6	650	.361	.12	1.59	333
54	250			.649	.195	2.49	300
55	400			1.11	.26	3.38	234
56	600			1.48	.29	4.314	196
57	720			1.85	.25	3.14	135
58	800			2.07	.26	4.34	125
59	1050			2.55	.19	2.54	74
60	150	.4	650	.28	.08	1.13	285
61	250			.445	.13	1.75	292
62	370			.648	.195		301
63	300			.704	.18	2.38	256
64	450			.815	.215		264
65	520			.889	.20		225
66	600			1.10	.24	3.19	218
67	720			1.26	.19	2.39	151
68	800			1.39	.24	3.29	173
69	1050			1.85	.155	2.14	84
70	1220			2.04	.26		127
71	1700			2.22	.26		117
72	2000			2.89	.03		10

(continued)

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DATE: 13 Jan 1954

TABLE 5.7
(continued)

REC. PHOTO	PULSE FREQ. cps	PULSE LENGTH $\times 10^{-3}$	VALVE FORWARD RESIST- ANCE ohms	TOTAL SOURCE CURRENT ma	INPUT VOLT. volts	VALVE INPUT CURRENT and LINE OUTPUT CURRENT ma	SPEC. THRUST ohms
73	150	.28	650	.222	.065	.86	293
74	250			.342	.10	1.36	292
75	400			.555	.15	1.9	270
76	600			.815	.20	2.61	246
77	720			.945	.15		159
78	800			1.07	.22	2.9	205
79	880			1.18	.23		206
80	1050			1.39	.13	1.70	93
81	1240			1.66	.27		165
82	1530			2.04	.27	3.57	132
83	150	.17	650	.148	.05	.628	338
84	250			.231	.08	1.01	346
85	400			.379	.125	1.58	330
86	450			.453	.145		321
87	600			.564	.17	2.16	301
88	710			.67	.110		164
89	800			.768	.20	2.52	260
90	890			.834	.20		240
91	1050			1.01	.105	1.44	104
92	1240			1.14	.245	3.13	215
93	1420			1.31	.225		172
94	1600			1.39	.25	2.88	180
95	2150			1.78	.03	.504	17
96	250	.13	650	.0835	.025	.381	298
97	400			.167	.045	.598	268
98	600			.24	.07	.821	292
99	800			.298	.10	1.05	335

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or Changed to

Authority: *General* *JADC*

By: *Pittman*

Date: *19 May 54*

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